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# Modeling Access to Wind Resources in the United States

W.D. Short

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**National Renewable Energy Laboratory**

**1617 Cole Boulevard**
**Golden, Colorado 80401-3393**

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# Modeling Access to Wind Resources in the United States

Walter D. Short
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden CO 80439
USA

## Abstract

To project the United States' potential to meet future electricity demands with wind energy, estimates of available wind resource and costs to access that resource are critical. The U.S. Department of Energy (DOE) Energy Information Administration (EIA) annually estimates the U.S. market penetration of wind in its Annual Energy Outlook series. For these estimates, the EIA uses wind resource data developed by the Pacific Northwest National Laboratory for each region of the country. However, the EIA multiplies the cost of windpower by several factors, some as large as 3, to account for resource quality, market factors associated with accessing the resource, electric grid impacts, and rapid growth in the wind industry. This paper examines the rationale behind these additional costs and suggests alternatives.

## Introduction

The U.S. Department of Energy (DOE) Energy Information Administration (EIA) annually estimates U.S. market penetration of wind in its Annual Energy Outlook (AEO) series (EIA 1998a). In Figure 1, the AEO99 reference case shows wind penetration by the year 2020 in the United States to be only 3.6 gigawatts (GW), less than a doubling of today's capacity. This low growth can be attributed largely to the essentially level natural gas prices that are part of the reference case as simulated in the EIA's National Energy Modeling System (NEMS).

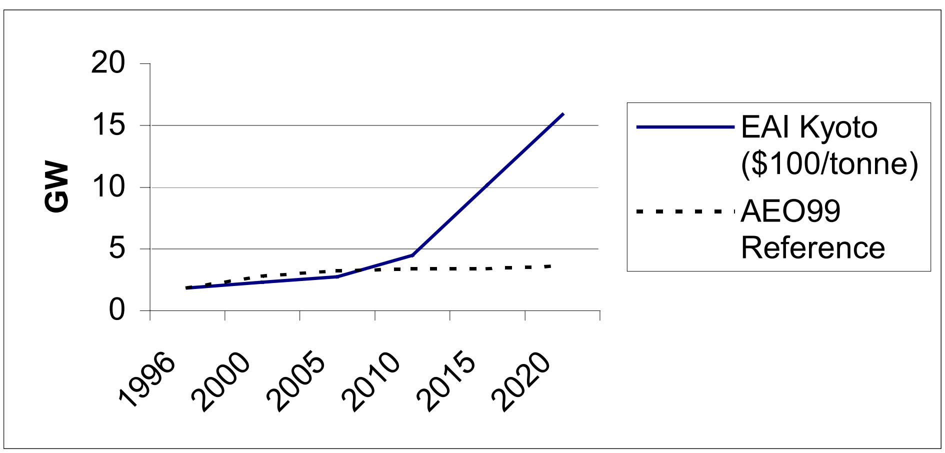


**Figure 1 Projections of Wind Market Penetration in the United States**

The EIA has recently used NEMS to venture into the policy analysis arena where it has estimated the cost of reducing U.S. carbon emissions (EIA 1998b). Wind is one of the options considered by the EIA for displacing carbon-emitting, fossil-fired power plants. Also shown in Figure 1, the EIA estimates that use of wind power will grow to 16 GW by 2020 with a carbon tax that grows to $100/tonne by 2020[1]. While this is certainly large relative to the EIA's reference case, it is not large considering the size of U.S. wind resources, the falling cost of wind power, and that $100/tonne of carbon equates to a penalty on coal plants of about 2.5 cents per kilowatt hour (kWh).

Our independent analysis (Short 1998) shows that over 100 GW of wind could be cost effective by 2020 if carbon emissions are valued at $50/tonne, even assuming the EIA's level natural gas prices in the future. This discrepancy led us to examine the wind assumptions of the EIA's model in great detail. This investigation revealed discrepancies between the model and its documented treatment of wind. The EIA is moving to fix these. However, the EIA documentation (EIA 1998a) also reveals a number of constraints and cost modifications to wind.

## EIA Modeling of Wind

The NEMS version used by the EIA to develop their AEO99 reference case contains five major wind constraints/cost multipliers:

- Long-term multipliers on the capital cost of wind for resource access
- Short-term price elasticity for wind
- Maximum limit of 10% of the generation in a single region
- Restrictions against building wind in one NERC region to provide power to another region
- Maximum of one GW built in a single region in a single year

Figure 2 shows that these constraints have a huge impact on the forecasted penetration of wind when a carbon tax of $100/tonne is imposed on all carbon emissions. While the EIA estimate for this case yielded only 16 GW of wind by 2020, NEMS forecasts that up to 214 GW of wind could penetrate by 2020 with the constraints removed.

Figure 2 also shows that the sequence in which the constraints are removed determines the impact of each constraint. For example, in the case where all the constraints are removed, it appears that the constraint on interregional builds is the more restrictive constraint. However, when interregional builds are allowed, as shown by the middle set of columns in Figure 2, the intermittency limit becomes a bigger factor. Similarly, if the long-term access multiplier is reinserted as shown by the furthest right set of columns in Figure 2, it appears to be the most restrictive constraint. Multiple sensitivity analyses with NEMS leads us to believe that the first two constraints listed above—long-term multipliers for resource access and the short-term price elasticity—are two of the more restrictive constraints. We examine these two in detail below.

## Long-Term Multiplier on Wind Capital Cost for Resource Access

Table 1 shows that in NEMS, wind capital cost is multiplied by either 1, 1.2, 1.5, 2, or 3, depending on the amount of wind resource that has been accessed in each region. The regions included in Table 1 are the regions with the largest wind resource. One of the rationale for these cost multipliers (Petersik 1999) is that some early regional wind resource reviews showed considerably less wind resource in their region than that estimated by the Pacific Northwest National Laboratory (PNNL) wind resource data used by the

[1] The $100/tonne in 2020 results are from the case described by EIA as 1990 + 24% (EIA 1998a).

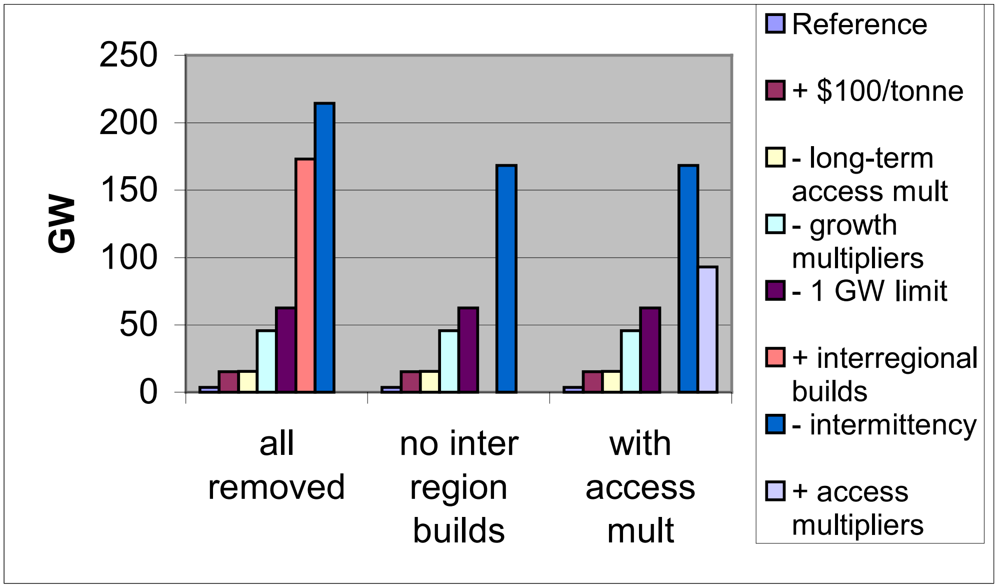


**Figure 2 Impact of Constraints on Wind in NEMS in 2020**

EIA. A 1996 Northwest Power Planning Council study (NWPPC 1996) for wind sites in Idaho, Montana, Oregon, and Washington provided the most detailed resource data. The NWPPC study showed that only 1.3 - 4.3 GW of wind resource are available in these states. On the other hand, for the slightly larger NERC Pacific Northwest region (NWP), PNNL data show a potential of 315 GW.

**Table 1**
**Long-Term Capital Cost Multipliers in NEMS for Selected Regions**

| | Fraction of Region's Wind Resource | | | | |
|---|---|---|---|---|---|
| **Multiplier** | **1** | **1.2** | **1.5** | **2** | **3** |
| MAPP | 1% | 1% | 3% | 3% | 92% |
| SPP | 1% | 1% | 3% | 3% | 92% |
| NWP | 3% | 4% | 3% | 0% | 90% |
| RA | 2% | 2% | 4% | 10% | 82% |
| CNV | 12% | 4% | 3% | 4% | 77% |

To identify the source(s) of this discrepancy, we developed a GIS map of the NWPPC sites overlaid on the PNNL data. Figure 3 shows this overlay for the state of Washington with the PNNL resource data shown as grid squares that are 1/3 degrees in longitude wide and 1/4 degrees in latitude high.

Two types of NWPPC sites are shown. The asterisks are sites that they judged on the basis of wind speed (>12 mph), measurement period (> 8 months of data), and land area (>1 square mile) to be acceptable. All other symbols are sites that were rejected because they did not meet one of the above criteria. According to the NWPPC and as can be seen from this overlay, there are very few acceptable wind sites in the state of Washington. On the other hand, the PNNL database shows a plethora of areas with wind resources of class 3 or better.

Similarly, for the Pacific Northwest as a whole, the NWPPC study shows only 44 sites, while the PNNL database has 860 grid squares, portions of which contain wind resources of class 3 or better[2]. Furthermore, five of the NWPPC sites selected are not in any of the PNNL grid squares.

[2] Some sites were so close together that they were combined in the NWPPC study yielding a total of 39 sites.

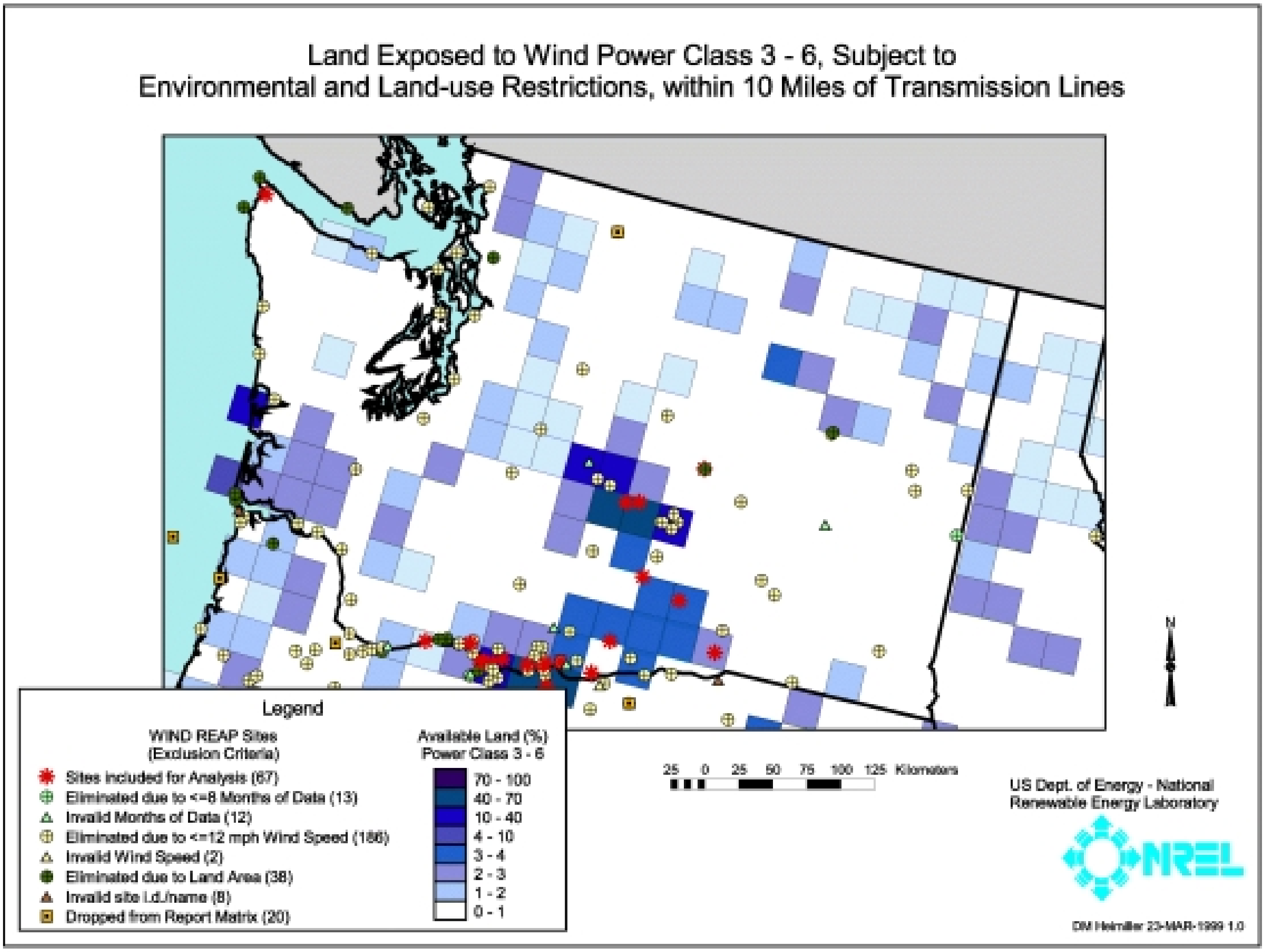


**Figure 3 NWPPC Sites Overlaid on PNNL Resource Estimates**

To try to resolve these discrepancies we contacted the principal developers of both the NWPPC and PNNL databases. We found many reasons for the discrepancies and found that differences in the approaches qualitatively explain much of the difference in the results.

First, the two studies used entirely different approaches. The PNNL study was a nationwide effort that evolved from 1979 through the publication of the *Wind Energy Resource Atlas of the United States* in 1987 (Elliott, et al. 1987). Refinements were made in 1991 and 1995, to limit the sites by land use and environmental considerations (Elliott, et al. 1991) (see Table 2 for the values represented in Figure 3) and to further limit the sites by access to transmission lines (Parsons 1995). The PNNL study built on 12 regional wind energy resource atlases where the majority of the data were from "anemometer heights and locations that were not chosen for wind energy assessment purposes" (Elliott, et al. 1987). With this starting point new site data were identified and obtained for practically every region of the United States with approximately 200 of these new sites instrumented specifically for wind.

**Table 2**
**Environmental and Land-use Exclusions for the PNNL Moderate Exclusion Case**

| Environmental Exclusions | Land Use Exclusions | Transmission Access |
|---|---|---|
| National parks and monuments<br>Wilderness areas<br>Wildlife refuges | Urban 100%<br>Wetland 100%<br>Forest 50%<br>Agriculture 30% | Within 10 miles of existing Transmission |

NWPPC data are based on a 5-year Wind Regional Energy Assessment Program conducted by the Bonneville Power Administration (BPA) beginning in 1980. The program analyzed 300 sites and concluded "that there are 39 areas that have wind energy development potential" (Baker 1985). The report also states that "The fullest extent of the resource may be somewhat larger than that described by the findings as not all potentially high wind areas were monitored."

We explored this key statement found at the end of the summary of the document with the author, Bob Baker. We found that, as with many studies of this sort, there were a number of limitations precluding a comprehensive exploration. Primarily, these included a limited budget, technological shortcomings, and legal access. We also discovered from Mr. Baker that the principal means for identifying sites for instrumentation was a series of aerial surveys. In the course of this and earlier efforts, Mr. Baker and his associates had developed a capability to classify wind resources by the "flagging" of trees. "Bushes and trees exposed to persistently strong winds exhibited a wind swept form with most of the vegetation on the lee side of the main stem while grasses appeared in clumps, clipped short and aligned with the prevailing wind. Often on exposed hills and ridges the vegetation took a sculptured form as it was clipped or swept by the strong winds" (Baker 1985).

Based on this tree flagging data and other sources, Mr. Baker had recommended that 95 sites be instrumented with anemometers for wind resource assessment. According to Mr. Baker, this number would have been even larger had there not been restrictions on obtaining permits to place anemometer towers on federal lands, limited access to some privately held parcels, and budget limitations. Only 23 of the 95 recommended sites were instrumented. Particularly limiting was the availability of battery-operated anemometers, which meant that the large majority of sites instrumented had to have access to AC power—not a likely event for most potential wind sites.

To provide a more comprehensive, albeit slightly less certain, estimate of the wind resources in the BPA service area, we asked Mr. Baker to provide his original aerial surveyed tree flagging data. Figure 4 shows these data also superimposed on the PNNL data for the state of Washington. This overlay shows much more agreement between the PNNL data and the potential identified in the NWPPC and BPA studies.

For the BPA service area as a whole, the tree flagging data expand the number of potential sites from the 39 included in the NWPPC report to 429 with class 3 winds or better—45 sites of which are class 4 or better. Obviously additional investigation of these sites to include anemometer readings, access resolution, and other considerations is needed to ensure their viability before actual wind installations can be pursued. But for the purpose of estimating future wind potential, these additional sites should be included in any analysis. They fill out the potential identified by the BPA, which wasn't interested so much in the comprehensiveness of its study but rather in knowing if "a significant potential wind resource does exist in the region" (Baker 1985).

The EIA also used state-level reports for California and Minnesota. We have not conducted the same level of investigation into these data, although Sezgen (1998) has used the California data to show significant potential without the cost penalties assumed by the EIA for that region. It is certainly not possible to extrapolate the findings of any of these regional reports to the rest of the country as the terrain, political issues, social concerns, and regulatory environments vary considerably.

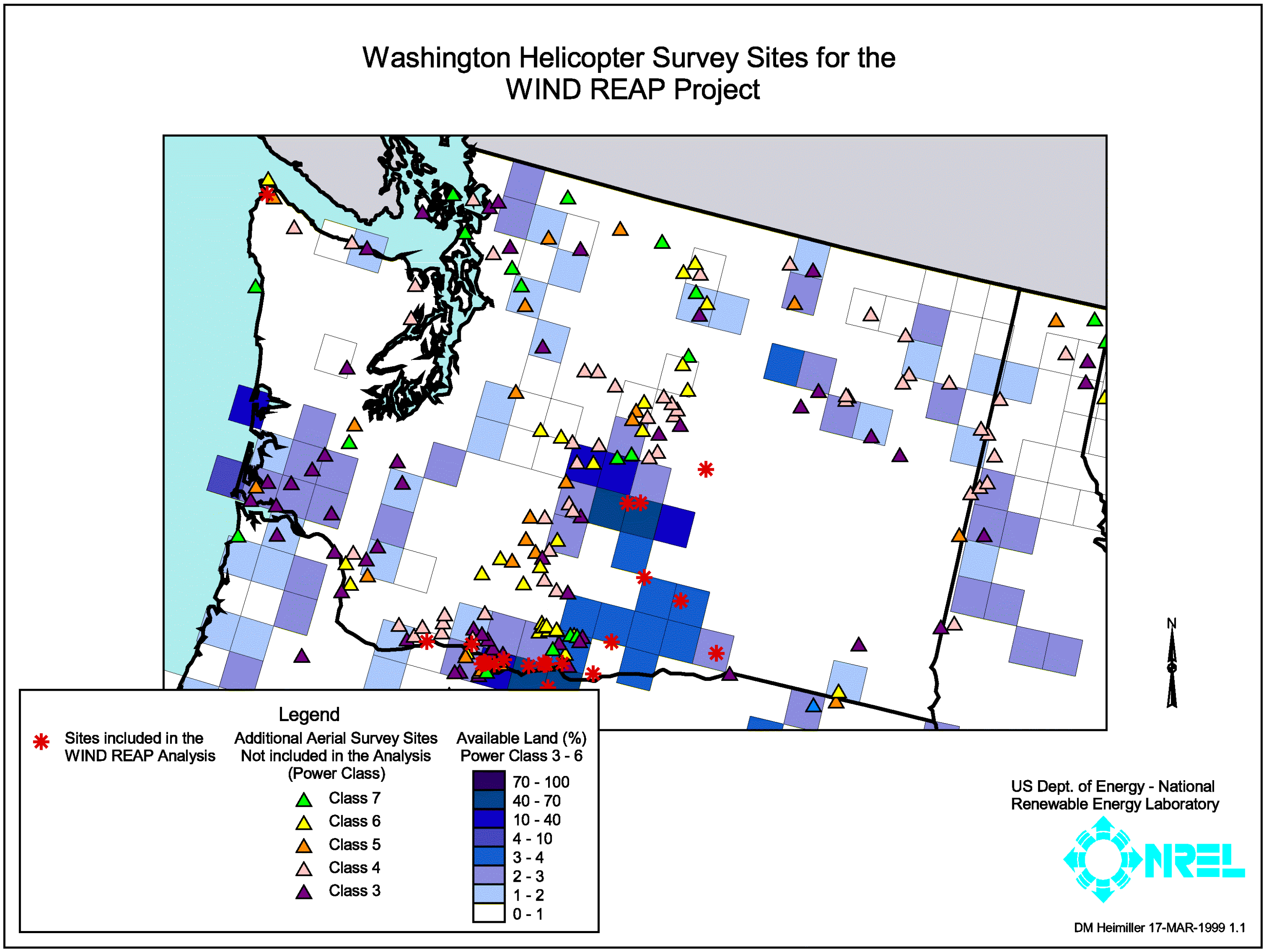


**Figure 4 Tree Flagging Data Overlaid on PNNL Resource Estimates**

## Short-Term Price Elasticity for Wind

A second, severely-limiting constraint on wind within NEMS is a short-term price elasticity for wind. Short-term price elasticites are a well-established economic concept that capture the fact that as short-term demand for a product rises, suppliers will naturally increase their price to bring supply and demand back into balance. In the NEMS model, the EIA implements a form of the elasticity concept by increasing the capital cost of wind by 1% for each 1% increase in the capacity of wind deployed nationwide above 20% in a single year[3]. Unfortunately, the EIA has not been able to empirically derive its elasticity values. We also find that the rapid number of developments in the infant wind industry, the proprietary nature of cost information, and the international arena in which the industry operates currently preclude us from developing statistically reliable estimates of the short-term price elasticity for wind.

Nonetheless, there is qualitative evidence that indicates that the connection between wind prices and total wind installations in the United States is not as strong as the EIA assumes. Figure 5 shows that the rapid growth of wind in California in the early 1980s was accompanied by a decrease in wind prices, not an increase. Obviously many factors other than short-term supply

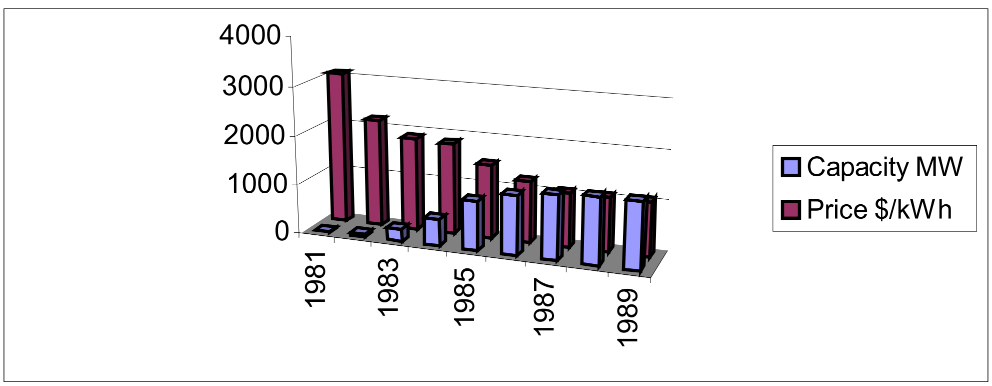


**Figure 5 California Wind Energy History**

and demand balance influenced these prices. But annual growth in total installations of almost 100% in 1984 and 1985, accompanied by decreases in price, provides no support for the EIA contentions.

Similarly, international markets have recently shown huge growth in installations. Figure 6 shows growth in a number of countries has far exceeded the 20% growth in total installations in a single year at which EIA starts to impose a price penalty. International growth as a whole was 35% in 1998. Due to the proprietary nature of price information, it is difficult to obtain direct information that would support or disprove any contention that the significant international

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[3] This is an oversimplification of what actually occurs in NEMS. Because NEMS employs a linear program it must break this formulation into a limited number of discrete blocks. NEMS currently uses three blocks with the first representing the 20% in new orders that incurs no cost penalty, and the latter two set to approximate the 1% penalty for each 1% in new orders above the 20% in the first block. In the AEO99 Reference Case (EIA 1998a) the approximation was particularly poor. The last two blocks were so large that any order larger than 20% of current installations received at least a 70% penalty. We understand that EIA is correcting this error for their next *Annual Energy Outlook.*

growth in wind installations over the last few years resulted in price increases. Perhaps the best data we have found are the production and sales revenues of the Danish wind industry, which accounts for half the world's wind exports. Figure 7 shows a declining ratio of income to production, suggesting if anything, a decline in prices at the same time production is increasing.

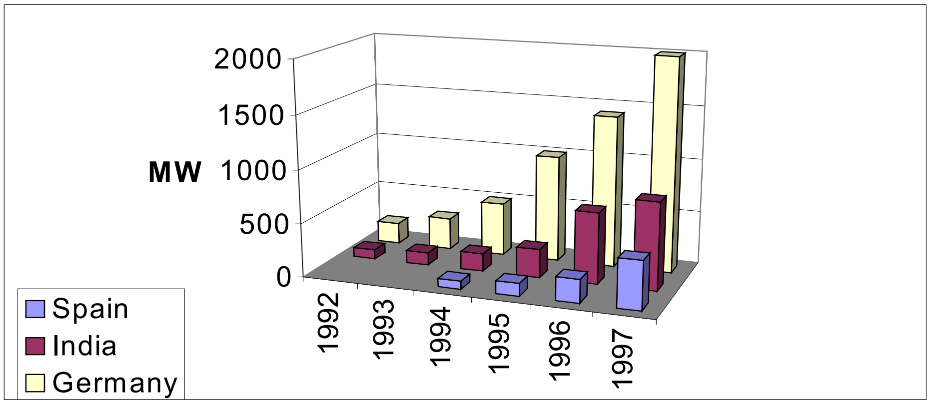
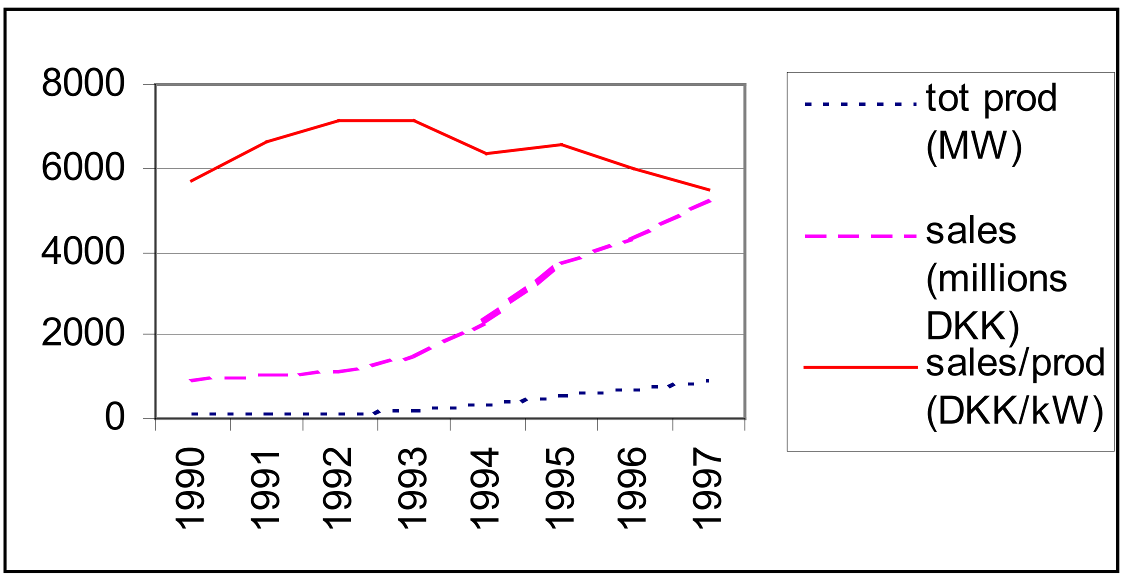



**Figure 6 International Wind Energy Growth in Installations**




Source: http://www.windpower.dk/stat/index.htm August 31, 1999

**Figure 7 Danish Wind Industry Statistics**

## Conclusions

Several regional agencies have made estimates of the wind potential in their region. While these generally have shown substantial wind resources, they were not always designed to show the full extent of the wind potential. Our investigation of the NWPPC report and the study behind it leads us to conclude that there is significant additional wind potential in the Pacific Northwest that is not captured by the NWPPC report. The EIA has used these state-level estimates as a primary guide in constraining their estimates of wind potential both in the Pacific Northwest and nationally in the NEMS model and the *Annual Energy Outlook 1999*. Such an extrapolation requires a detailed examination of the methods, financial resources, and purpose of the studies. Furthermore, the terrain, social issues, cultural history, political issues, and regulatory environments which drive many of the wind siting considerations and costs in the Pacific Northwest cannot be assumed to exist in the other regions of the country.

In the past two decades, wind has experienced several periods of rapid growth, both in this country and abroad. We can find no documented evidence that this growth has produced significant price increases for wind systems.

## Acknowledgments

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